TYPHOON AND TROPICAL STORM INTENSITY
FORECASTS USING
STATISTICAL REGRESSION EQUATIONS

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THESIS

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by

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March 1973

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
March 1973

ABSTRACT

Statistical regression equations were derived to predict future 24-hour changes in intensity of tropical storms and typhoons in the western North Pacific. The predictors were chosen from 55 parameters available at six-hourly observations of tropical storms and typhoons during the period 1960-1969. The dependent data were composited into six categories: east-west moving storms, recurving storms, and all storms within latitude bands 0-9.9N, 10-19.9N, 20-29.9N and 30-39.9N.

The forecast equations were evaluated on a five-year (1955-1959) sample of independent data and compared to the forecast verification scheme employed by Fleet Weather Center/Joint Typhoon Warning Center. Two five-predictor equations, which require only 12 hours of history, can predict intensity for the majority of storms within the period July-September, and give significantly better results than current intensity forecast methods.

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Russell L. Elsberry, faculty advisor, for his advice, guidance and support throughout this research.

Appreciation is also expressed to Dr. Frank L. Martin for his guidance in interpretation of statistical results, and to Dr. R. J. Renard for his careful review of the manuscript.

Appreciation is also expressed to the W. R. Church Computer Center Facility of the Naval Postgraduate School.

Finally, and most importantly, a very grateful thank you to my wife Judy, for her patience and understanding throughout this period of study.

I. INTRODUCTION

Intensity (maximum wind) forecasts are one of the more difficult aspects of present-day typhoon forecasting. The processes governing the intensification of tropical cyclones are very complex and not well understood; consequently, there is relatively little information available to aid the forecaster. Historically, more emphasis has been placed on the storm-movement forecast rather than storm intensity, since an intensity forecast was of little value to the local forecast if the storm-track prediction was inaccurate. Only recently, with the increased accuracy of track forecasts, has attention turned to intensity. The Joint Typhoon Warning Center, Guam (FWC/JTWC), did not attempt to verify intensity forecasts prior to 1969. The basic intensity forecasting technique used by FWC/JTWC is a linear extrapolation of past change in intensity subjectively modified by expected conditions along the predicted track (FWC/JTWC 1970).

A diagnostic approach can be applied to intensity forecasting of tropical cyclones by considering such factors as sea-surface temperature, characteristics of the warm air mass in which the storm is embedded, and synoptic features expected along the predicted storm track. This approach mainly indicates whether a tropical cyclone will intensify or weaken as it proceeds along the predicted track.

Current emphasis is being placed on climatological studies of tropical cyclone intensification, and these studies are essentially the only quantitative guidance available to the intensity forecaster. Gray (1970) has provided a general updated climatology and physical theory of tropical cyclones in the western North Pacific. A study based on 25 years (1945-1969) of data by Brand and Gaya (1971) offers geographic and seasonal variations of tropical cyclone intensity changes for 12, 24 and 48 hours. More recently Liechty (1972) has demonstrated monthly variations of intensity of tropical cyclones.

Although climatological guides are now available to aid the forecaster in predicting the future intensity of tropical cyclones, the purpose of this study is to provide the forecaster with an additional tool to forecast the future 24-hour intensity of tropical cyclones in the western Pacific. This tool will be in the form of prediction equations, derived using statistical regression techniques, which will quantitatively predict the future 24-hour change in intensity of tropical cyclones.

II. DATA

A. DATA SOURCE

The data used in this study were obtained from the Naval Environmental Prediction Research Facility, Monterey, California. The data source consisted of a history file of six hourly information on tropical storms[1] and typhoons[2] (hereafter referred to as storms) which occurred in the western North Pacific Ocean during the period 1945 through 1969 and are based on post-season analysis. These data were compiled by the National Climatic Center, Asheville, North Carolina, for the Navy Weather Research Facility, Norfolk, Virginia, and have served as the basis for several studies on intensity of tropical storms and typhoons (Brand and Gaya 1971). More recently, the same data were used in a study of intensity changes of tropical cyclones for the period 1960-1969 (Liechty 1972).

B. DEPENDENT DATA SAMPLE CRITERIA

Data were chosen for the dependent sample from the years 1960 through 1969, since it was felt that the last few years of wind data would be the most complete and accurate considering the increased use of Doppler radar. Following Liechty (1972), it was decided to eliminate storms of the following categories:

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[1] Tropical cyclonic circulation which attains tropical storm intensity (34-63kt) at one time in the life of the storm.

[2] Tropical cyclonic circulation which attains typhoon intensity ($\geq$ 64kt) at one time in the life of the storm.

1. Storms with an initial northeasterly heading which continued to move to the northeast.

2. Storms which had a genesis west of 125E.

3. Looping storms, i.e. storms which formed a complete loop in the track.

4. Storms with the first observation reporting a maximum intensity greater than 65 knots.

In addition, each tropical cyclone was required to have a 48-hour history. Due to the strong effects of terrain on the behavior of tropical cyclones, as suggested by Brand (1972), only those storms with continuous track segments over open ocean were considered. When a storm track reached land, the data were discontinued at the preceding six-hourly observation time.

Considering the large variability in the storm tracks, the data were first classified into two categories:

1. East-west moving storms, i.e. storms moving predominately in a westerly direction and not looping or recurving.

2. Recurving storms, i.e. storms which changed direction of movement in a clockwise direction from a westerly to an easterly component.

The data were further classified into monthly periods, since tropical cyclones exhibit significant monthly and seasonal variations in intensity (maximum surface wind)(see Liechty 1972). Table I is a summary of the dependent data

TABLE I

Dependent data summary with means and standard deviations of future 24-hour change in intensity.

(a) East-West Moving Storms

Period	Number of Storms	Number of Six-hourly Observations	Mean	Std. Dev.
July	18	250	1.8	23.0
August	22	179	9.8	26.2
September	25	319	4.6	21.3
October	8	75	9.1	22.6
November	8	102	6.9	19.3
Dec-Jun	17	149	5.3	23.1
Jul-Aug-Sep	65	748	4.9	23.3

(b) Recurving Storms

Period	Number of Storms	Number of Six-hourly Observations	Mean	Std. Dev.
July	2	41	-1.5	11.5
August	12	250	0.9	19.4
September	13	321	3.0	20.1
October	20	380	1.5	22.5
November	9	206	1.5	22.3
Dec-Jun	12	246	-0.4	23.6
Jul-Aug-Sep	27	612	1.8	19.4

sample grouped by months in the east-west and recurving categories.

The data included storms which both intensified and weakened and many which went through a complete cycle of intensification and weakening. Since all storms were only considered over open ocean, all of the track over land was eliminated, thus biasing the sample somewhat in favor of storms which intensified. The magnitude of the means of the future 24-hour change in intensity was in general larger in the east-west moving storms than in the recurving storms, and all mean values were positive in the east-west storms. The largest mean values occurred in August and September storms. The standard deviations were slightly larger in east-west moving storms; however, the standard deviations of both east-west and recurving storms are very similar in magnitude. The largest standard deviation of future 24-hour change in intensity occurred in August east-west moving storms. These means and standard deviations cannot be compared to the work done by Liechty (1972) since he was concerned with actual intensities rather than changes. Since all observations were over open ocean, the weakening of many east-west moving storms was not seen in the data, due to discontinuing data 24-hours prior to landfall. However, the entire track of most recurving storms was observed, thus accounting for a much larger mean value of future 24-hour change in intensity of east-west moving storms.

In the western Pacific, the frequency of occurrence of typhoons is correlated with potential instability and water temperature. Temperature is thought to be an important factor in tropical cyclone intensity, and intense tropical cyclones are confined to areas with warm surface waters (Palmen and Newton, 1969). In view of the fact that temperature information was not available in this data, the data were also stratified into four latitude bands from 0-9.9N, 10-19.9N, 20-29.9N and 30-39.9N. Stratification of data in this manner, to a certain extent, took into account the variation of sea-surface temperature with latitude in the Pacific. The data stratified by latitude bands were classified into monthly periods. Table II is a summary of dependent data stratified into latitude bands.

When examined in latitude bands, the mean values of future 24-hour change in intensity were positive in the lower latitudes, 0-20N. At higher latitudes, 20-40N, the mean value of future 24-hour change in intensity decreased to a small positive value in August and negative values in all other months. The largest mean value was observed in intensifying August storms, in the 10-19.9N latitude band, and in the weakening Nov-Dec storms within 20-29.9N. As storms moved northward out of warm southern waters, they would be expected to weaken, and this was particularly evident in the winter and spring storms (Nov-Jun) moving from 10-19.9N to 20-29.9N.

TABLE II

Dependent data summary in latitude bands with means and standard deviations of future 24-hour change in intensity.

Period	Number of Six-hourly Observations	Mean	Standard Deviation
(a) 0-9.9N			
Jan-Dec	190	11.2	19.5
(b) 10-19.9N			
Dec-Jun	251	3.3	23.0
July	136	10.6	19.9
August	122	15.2	22.9
September	288	12.7	21.0
October	227	13.3	20.1
November	197	6.7	18.1
Jul-Aug-Sep	546	12.7	21.2
(c) 20-29.9N			
Nov-Jun	90	-22.1	19.0
July	132	-5.9	20.7
August	211	2.3	23.2
September	330	-3.5	17.0
October	217	-7.1	20.1
Jul-Aug-Sep	673	-2.2	20.1
(d) 30-39.9N			
Jan-Dec	127	-12.2	12.3

The standard deviation of future 24-hour change in intensity was generally smaller when categorized into latitude bands, thus indicating the importance of subtracting out different means in different latitudes. However, the standard deviations were still rather uniform.

C. INDEPENDENT DATA SAMPLE CRITERIA

The independent data sample used for equation verification were chosen from the years 1955 through 1959. Storms in the months of July, August and September were chosen for verification. Once again, only observations of storms over open ocean were used. The data were not divided into east-west or recurving categories, because it would be impossible to know in the early stages if a storm was going to recurve. Storms of the following categories were eliminated:

1. Northeasterly moving storms which had an initial northeasterly heading.
2. Storms which had a genesis west of 125E.
3. Storms with the first observation reporting a maximum intensity greater than 65 knots.
4. Looping storms.

Each tropical cyclone was required to have a 48-hour history, and data were discarded 24 hours prior to landfall, to allow 24-hour forecasts only over open ocean.

The data were considered in monthly periods, and were also stratified into four latitude bands. Table III is a summary of the independent test data. The mean values of the future 24-hour change in intensity of the independent

TABLE III

Independent data summary by month with means and standard deviations of future 24-hour change in intensity.

(a) Monthly Category

Period	Number of Storms	Number of Six-hourly Observations	Mean	Standard Deviation
July	11	174	1.9	23.1
August	12	158	6.1	19.8
September	16	253	8.3	23.4

(b) Latitude Band 0-9.9N*

(c) Latitude Band 10-19.9N

Period	Number of Storms	Number of Six-hourly Observations	Mean	Standard Deviation
July		69	18.6	15.0
August		75	17.5	19.3
September		140	15.1	20.6

(d) Latitude Band 20-29.9N

Period	Number of Storms	Number of Six-hourly Observations	Mean	Standard Deviation
July		92	-9.3	21.3
August		70	-2.4	18.5
September		112	-0.3	24.1

(e) Latitude Band 30-39.9N*

* Indicates that this Latitude Band was not evaluated due to small number of observations. There was 1 observation within 0-9.9N and 26 observations within 30-39.9N.

sample were negative at higher latitudes, just as in the dependent sample data. Likewise, the standard deviations were in general smaller when stratified into latitude bands, just as in the dependent sample. The largest mean values again occurred in August and September storms. The standard deviation of the future 24-hour change in intensity of the independent sample is similar to the standard deviation of the dependent sample.

D. DESIGNATION OF DATA

The variables available for this study are listed in Table IV. Variables Z_1 through Z_{16} were obtained as original data from the Environmental Prediction Research Facility. These parameters were originally derived for use as analog data elements in a study of typhoon movement prediction through analogs by Jarrell and Somervell (1970). Variables Z_{17} through Z_{22} were derived to have available past changes of intensity, latitude and longitude. Variables Z_{23} through Z_{38} were computed as "perfect forecast" parameters. Several of the parameters were combined or manipulated to describe large scale synoptic factors related to storm location and intensity. Z_{39} and Z_{41} were used to generate Z_{42} which is a gradient value of 700mb ridge height difference divided by latitude separation of the 700mb ridge and the storm. Z_{43} and Z_{44} were used to generate Z_{45} which is a gradient measure of 700mb trough height difference divided by the longitude separation of the 700mb trough and

the storm. A number of predictors were formed by ratios and differences of parameters which Liechty (1972) related to storm intensity. Z_{40} (intensity minus minimum sea-level pressure) is such a relation of intensity and sea-level pressure. Z_{46} (maximum intensity divided by storm size) is a measure of the relative strength and size of the storm. Storm size is defined as the average radius, in degrees latitude, of the outer closed isobar. Variables Z_{47} and Z_{48} were used to generate Z_{55} which is a relative measure of the past 12-hour changes of intensity and size. To avoid dividing by zero, if the past 12-hour change in size were zero, the constant 10.0 was added to Z_{47}, and likewise added to Z_{48}. Parameter Z_{49} (square of maximum intensity) was generated to provide a second order variable, and Z_{50} (square of intensity divided by size) was designed as a relative measure of intensity with respect to size. Although sea-level pressure and intensity are highly correlated, Z_{51} (intensity divided by sea-level pressure) was created as a relative measure of intensity and sea-level pressure. A measure of the speed of movement related to intensity of the storm was formed as Z_{52} (24-hour speed divided by intensity). Z_{53} (700mb minimum height minus sea-level pressure) was a measure of thickness of the storm. Z_{54} (past 24-hour change in intensity divided by size) was designed as a relative measure of intensification and size of a storm.

TABLE IV

Sea-level (and 700MB where specified) predictors available at each six-hourly observation.

Z_i	Variable
1	Latitude-degrees and tenths
2	Longitude-degrees and tenths
3	Past 12-hour direction
4	Past 12-hour speed, in knots
5	Past 24-hour direction
6	Past 24-hour speed
7	Size-the average radius of the outer closed isobar, in degrees latitude
8	Past 12-hour change in size, in degrees latitude
9	Minimum sea-level pressure, in mbs
10	Past 12-hour change in sea-level pressure, in mbs
11	Maximum intensity-maximum surface wind speed, in knots
12	Minimum 700mb height in tens of meters
13	700mb ridge latitude-north of storm, in whole degrees
14	700mb ridge height-at ridge line north of storm in tens of meters
15	700mb trough longitude-at 35°N-nearest trough west of storm, in whole degrees
16	700mb trough height-at intersection of trough line at 35°N in tens of meters
17	Past 12-hour change in intensity
18	Past 24-hour change in intensity
19	Past 12-hour latitude change
20	Past 12-hour longitude change
21	Past 24-hour latitude change
22	Past 24-hour longitude change
23	Future 12-hour latitude change
24	Future 12-hour longitude change
25	Future 12-hour 700mb ridge latitude change
26	Future 12-hour 700mb ridge height change
27	Future 12-hour 700mb trough longitude change
28	Future 12-hour 700mb trough height change
29	Future 12-hour max intensity change
30	Future 24-hour latitude change
31	Future 24-hour longitude change
32	Future 24-hour max intensity change
33	Future 24-hour 700mb ridge latitude change
34	Future 24-hour 700mb ridge height change
35	Future 24-hour 700mb trough longitude change
36	Future 24-hour 700mb trough height change
37	Future 12-hour sea-level pressure change
38	Future 24-hour sea-level pressure change

TABLE IV
(Continued)

Z_i	Variable
39	700mb ridge latitude minus storm latitude (Z_{13}- Z_1)
40	Max wind speed minus minimum SLP (Z_{11} - Z_9)
41	700mb ridge height minus min 700mb height (Z_{14} - Z_{12})
42	700mb ridge HT DIFF/LAT SEP of 700mb ridge and storm (Z_{41}/Z_{39})
43	700mb trough height minus min 700mb height (Z_{16} - Z_{12})
44	700mb trough long. minus storm long. (Z_{15}-Z_2)
45	Trough HT DIFF/trough minus storm long. DIFF (Z_{43}/Z_{44})
46	Max intensity/size (Z_{11}/Z_7)
47	Past 12-hour change in size plus 10 (Z_8+10.0)
48	Past 12-hour change in max intensity plus 10 (Z_{17}+10.0)
49	Square of max intensity $(Z_{11})^2$
50	Square of max intensity/size (Z_{49}/Z_7)
51	Max intensity/SLP (Z_{11}/Z_9)
52	Past 24-hour speed/max intensity (Z_6/Z_{11})
53	700mb min height minus SLP (Z_{12} - Z_9)
54	Past 24-hour change in max int/size (Z_{18}/Z_7)
55	Past 12-hour change in max int +10.0/Past 12-hour change in size +10.0 (Z_{48}/Z_{47})

In this study, emphasis was placed on generating an equation to predict Z_{32}, the 24-hour future change in maximum intensity. However, equations to predict actual 24-hour future values of intensity were also derived for several categories and are presented in Appendix B.

Results are mainly presented for 24-hour future intensity changes, rather than actual intensity values. There are several papers concerning spatial and seasonal variations in 24-hour intensity changes which are available to the forecaster, namely Riehl (1971) and Brand and Gaya (1971). These papers can be consulted in conjunction with the use of the equations from this study.

III. PROCEDURES AND METHOD OF ANALYSIS

A. THE REGRESSION METHOD

Many problems in research require extensive analysis of large amounts of data. The Biomedical Computer Programs (Dixon 1966) were developed to provide programs for these commonly required tasks of data processing and statistical analysis. The program used in this study was the stepwise regression analysis program BIMED 02R.

BIMED 02R computes, in a stepwise manner, a sequence of multiple linear regression equations. One variable is added to the regression equation at each step. The variable added is the one which achieves the greatest reduction in the error sum of squares. This variable is also the one which has the highest partial correlation with the dependent variable at the particular step in the analysis of variance. Equivalently, it is the variable which would have the highest F-value if it were added. The F-value or F-statistic upon entry, F_k is expressed at step k as (Dixon 1966)

$$F_k\ (1,n-k-1) = \frac{\%\ (C.E.V.k) - \%\ (C.E.V.k-1)}{\%\ (U.E.V.k)}$$

where

%(C.E.V.k) is the percent cumulative explained variance at step k

%(C.E.V.k-1) is the percent cumulative explained variance at step k-1

%(U.E.V.k) is the percent unexplained variance remaining at step k

The F-value can be used to determine if a variable is statistically significant at a particular level. For example, a test at the 5% significance level whether the true partial regression coefficients are zero yields a critical F-value for particular degrees of freedom. As long as the F-value upon entry is larger than the critical F-value, it can reasonably be concluded that the variance accounted for by regression is greater than could be expected if all the true partial regression coefficients were zero (Crow, Davis, Maxfield 1955).

B. RELATED STATISTICAL PARAMETERS

Several related statistical parameters are available as outputs from the BIMED 02R program. Among these parameters are:

1. multiple correlation coefficient, R
2. standard error of estimate, S.E.
3. mean value, $\bar{I}$
4. standard deviation, σ
5. F-value

R is the simple correlation coefficient if only one predictor is added, and R becomes the multiple correlation coefficient after k predictors are added. The F-value becomes the overall F-value for the equation after k predictors are added. The overall F-value of the equation

can be compared to a critical F-value, for five predictors and a given number of independent samples, for a particular significance level to determine if the equation is statistically significant.

C. DERIVATION OF EQUATIONS

The BIMED 02R program was used to generate equations to predict future 24-hour change in intensity Z_{32}. The predictors were selected from parameters Z_1 through Z_{22} and Z_{39} through Z_{55} in Table IV. Variables Z_{23} through Z_{38} were not allowed as predictors since they were future parameters and would perhaps not be available to the forecaster. Thus the prediction equation would not contain any parameters other than those available from history or from a current aircraft observation. Since variables Z_{23} through Z_{38} were not allowed to enter as predictors in the regression equation, it was not determined if any of these parameters were of statistical significance and would indeed enter as predictors.

This study employed two statistical models to generate future 24-hour change in intensity I. The first model was of the form:

$$I=C_0+C_1N_1+C_2N_2+C_3N_3+C_4N_4+C_5N_5+C_6N_6+C_7N_7+C_8N_8+C_9N_9+C_{10}N_{10}$$

where C_0 through C_{10} and N_1 through N_{10} were determined by the stepwise, least squares technique. C_0 through C_{10} are constants and N_1 through N_{10} are predictors. The units

of I are knots per day. The second model was of the same form as the first, but was limited to five predictors. Although some parameters that were still of statistical importance were lost in using only five predictors, the loss of useful information was very little. The difference in results when using five predictors vice ten predictors will be discussed later.

All predictors composing each five-predictor equation were tested using the F-value upon entry of the predictor against a critical F-value (Crow, Davis and Maxfield 1955) and were found to be statistically significant at the 5% level. In addition, the overall F-value of each equation was compared to a critical F-value for a five-predictor equation, and each equation was found to be significant at the 0.5% level.

Regression equations to predict Z_{32} (future 24-hour change in intensity) using five predictors were first derived from the east-west dependent sample data in the following seven categories: (a) July (b) August (c) September (d) October (e) November (f) December through June and (g) July through September. A summary of the east-west data equations is found in Appendix A, Table X. In the east-west equations, variable Z_{50} (square of intensity divided by size) entered in five of the seven equations. Variables Z_{10} (past 12-hour change in SLP) and Z_{17} (past 12-hour change in intensity) each entered in four of the

seven categories. Variables Z_1 (current latitude) and Z_2 (current longitude) each entered in three of the seven categories.

Regression equations were next derived from the recurving dependent data in the same monthly categories as in the east-west dependent sample and are in Appendix A, Table XI. In the recurving data equations, variable Z_{10} (past 12-hour change in SLP) entered in each equation. Z_1 (current latitude) entered in six of the seven equations. Variable Z_{17} (past 12-hour change in intensity) entered in four equations.

If there should be a bias in a current storm and a prediction equation could be derived which would detect this bias and use it in a new equation as a predictor, the results of the new prediction equation could be improved. A scheme was tried whereby a ten-predictor equation was generated to predict Z_{18} (past 24-hour change in intensity). The predicted past 24-hour change in intensity derived from this equation was then subtracted from the actual past 24-hour change in intensity, thus generating an error parameter to represent a possible bias in the storm. The error was then made available as a variable for a ten-predictor equation to predict Z_{32} (future 24-hour change in intensity). This scheme was tried for two cases, September east-west data and August east-west data. In the September east-west case, the error parameter did not enter into the new ten-predictor equation to predict Z_{32} in the

stepwise, least squares technique. In the August east-west case, the error parameter did enter as a predictor, but the overall results of this new equation were not improved. The technique of generating an error to act as a measure of bias, and also show how well an equation was performing in the past to aid in generating a better equation for future predictions, did not prove to be useful in these two cases and was not tried further.

Regression equations to predict Z_{32} (24-hour future change in intensity) using five predictors were next derived from all data in the latitude band 10-19.9N for the same seven categories as in the east-west and recurving categories, and are located in Appendix A, Table XII. In these equations, variable Z_{10} (past 12-hour change in SLP) entered in six of the seven equations. Variable Z_{49} (square of current intensity) entered in four of the seven equations. Variables Z_1 (current latitude), Z_{17} (past 12-hour change in intensity), and Z_{50}(square of intensity divided by size) each entered in three equations.

Regression equations to predict Z_{32} (future 24-hour change in intensity) using five predictors were next derived from all data in the latitude band 20-29.9N for the following six categories: (a) July, (b) August, (c) September, (d) October, (e) July through September and (f) November through June. November storms could not be examined separately due to the small number of observations in November.

The equations to predict Z_{32} for 20-29.9N are presented in Appendix A, Table XIII. Variable Z_{10} (past 12-hour change in SLP) entered in five of the six equations. Variables Z_1 (current latitude), Z_{49} (square of current intensity), and Z_{50} (square of intensity divided by size) each entered in three of the six equations. It should be noted that latitude entered as a predictor even after separation by latitude, suggesting that perhaps a finer degree of separation could have been used.

There was not enough data in each monthly category for the latitude bands 0-9.9N and 30-39.9N to justify generating a prediction equation for each monthly period. Appendix A, Table XIV is a summary of the equations to predict Z_{32} (future 24-hour change in intensity) using five predictors. These equations were derived from all data within 0-9.9N and 30-39.9N.

D. EVALUATION OF EQUATIONS

1. Dependent Data Results

The multiple correlation coefficient, (R), and the standard error of the estimate, (S.E.), of each five predictor equation were compared to R and S.E. of persistence (past 24-hour change in intensity) when used for predicting the future 24-hour changes in intensity. A 24-hour forecast was made at each 6-hourly observation time using both the five-predictor equation and persistence (linear extrapolation). These forecasts were compared to actual future

24-hour changes in intensity. A tabulation of R and S.E. for both equation and persistence for each dependent-data category is presented in Table V. In each category, the correlation coefficient for predicting future 24-hour change in intensity was higher for the five-predictor equation than for persistence, and correspondingly, the standard error of the estimate was lower for the equation than for persistence.

In general, when using equations to predict future 24-hour changes in intensity, the larger the sample size, the smaller the correlation coefficient. The most difficult period to predict, i.e., the period with the smaller correlation coefficient, was the sample from the combined months of July, August and September. Using persistence to predict future 24-hour changes in intensity, a smaller correlation coefficient did not always correspond to a larger sample size. Overall, the prediction equation still gave better results than persistence, in each category.

2. <u>Independent Data Results</u>

The effectiveness of the statistical regression equations in predicting future 24-hour change in intensity was first examined as in the dependent data by looking at the correlation coefficient (R) and standard error of the estimate (S.E.). The predicted change in intensity was compared to actual future 24-hour change in intensity. R and S.E. for predicting future 24-hour change in intensity

TABLE V

Correlation coefficient (R) and standard error of estimate (S.E.) of five predictor equation and persistence for predicting future 24-hour change in intensity of dependent sample.

Equation Category	Sample Size	Equation R	Equation S.E.	Persistence R	Persistence S.E.
		a. East-West Data			
JULY	250	.73	15.9	.39	21.3
AUG	179	.65	20.1	.06	26.2
SEPT	319	.74	14.5	.53	18.1
OCT	75	.83	13.2	.26	22.0
NOV	102	.82	11.4	.53	16.4
DEC-JUN	149	.68	17.3	.29	22.2
JUL-AUG-SEPT	748	.66	17.5	.37	21.7
		b. Recurving Data			
JULY	41	.94	4.1	.84	6.3
AUG	250	.70	13.9	.32	18.4
SEP	321	.71	14.2	.45	18.0
OCT	380	.76	14.8	.40	20.6
NOV	206	.80	13.6	.48	19.6
DEC-JUN	246	.75	15.7	.37	22.0
JUL-AUG-SEPT	612	.69	14.1	.42	17.7
		c. 0-9.9N			
JAN-DEC	190	.74	13.2	.42	17.8
		d. 10-19.9N			
JULY	136	.78	12.7	.25	19.4
AUG	122	.78	14.6	.33	21.7
SEPT	288	.64	16.3	.44	19.0
OCT	227	.68	14.8	.31	19.1
NOV	197	.80	11.1	.28	17.5
DEC-JUN	251	.67	17.3	.29	22.1
JUL-AUG-SEPT	546	.63	16.5	.37	19.8
		e. 20-29.9N			
JUL	132	.69	15.3	.37	19.3
AUG	211	.64	18.0	.05	23.2
SEPT	330	.63	13.3	.39	15.7
OCT	217	.80	12.1	.26	19.5
NOV-JUN	90	.83	10.8	.27	18.4
JUL-AUG-SEPT	673	.59	16.2	.28	19.3
		f. 30-39.9N			
JAN-DEC	127	.58	10.2	.04	12.4

were compared with corresponding R and S.E. values for a forecast using only the past 24-hour change in intensity (persistence). These values are presented in Table VI for independent data. Just as in the dependent data sample, the correlation coefficient of the equation was higher in each category than that of persistence when predicting future 24-hour change in intensity. In general, equations from combined July, August, and September data gave higher correlation coefficients than equations derived from one month. The most difficult month to forecast was September, and the best results were seen in August when examining correlation coefficients. September was also the most difficult month when using only persistence, and July and August were about equal in forecasting with persistence.

A second, perhaps more timely method of evaluating the performance of each equation is the test recently used by the Fleet Weather Central/Joint Typhoon Warning Center at Guam, Marianas Islands. When considering the standard error of estimate (S.E.) and correlation coefficient (R), equal weight is given to the error in the future 24-hour change of intensity of a storm, regardless of the actual intensity of the storm. However, a 20 knot error in a very intense typhoon is not as important as the same error in a weak tropical storm. To overcome this deficiency, FWC/JTWC suggested describing errors as a fraction of the observed wind:

$$\text{Error} = \frac{\text{Forecast Intensity} - \text{Observed Intensity}}{\text{Observed Intensity}}$$

Some acceptability criteria (from the viewpoint of adequacy for disaster control planning) were established by FWC/JTWC for a 24-hour forecast as follows:

Accurate to within measurement error	Error ≤ 10%
Adequate	Error ≤ 20%
Useful	Error ≤ 30%
Inadequate	Error > 30%

The criteria became less stringent for 48-or 72-hour forecasts (FWC/JTWC 1970). The distributions of FWC/JTWC 1970 and 1971 24-hour intensity forecasts, according to acceptability criteria, were as follows (FWC/JTWC 1970 and EG PACOM 1972):

	1970	1971
Accurate to within measurement error	31%	25%
Adequate	54%	55%
Useful	70%	72%
Inadequate/Misleading	30%	28%

These results provide a guideline for evaluating the statistical regression equations using the independent sample from 1955-59. For example, a typical error of 10-15 knots in 24 hours could represent an accurate forecast for an intense typhoon or an inadequate forecast for a weak tropical cyclone.

a. Five-predictor equations derived from east-west and recurving data

A 24-hour forecast was made at each 6-hourly observation for data grouped by monthly periods. Since it

TABLE VI

Correlation coefficient (R) and standard error of estimate (S.E.) of persistence and five predictor equation for predicting future 24-hour change in intensity of independent sample.

a. July Data

Equation	Sample Size	Equation R.	Equation S.E.	Persistence R.	Persistence S.E.
July E-W	174	.73	16.0	.43	21.0
July Rec.	174	.53	19.6	.43	21.0
July 10-19.9N	69	.40	13.8	.26	14.6
July 20-29.9N	92	.59	17.3	.40	19.7
July-Aug-Sep:					
E-W	174	.74	15.7	.43	21.0
Rec.	174	.74	15.6	.43	21.0
10-19.9N	69	.54	12.7	.26	14.6
20-29.9N	92	.57	17.6	.40	19.7

b. August Data

Equation	Sample Size	Equation R.	Equation S.E.	Persistence R.	Persistence S.E.
Aug E-W	158	.75	14.1	.42	19.6
Aug Rec.	158	.79	13.1	.42	19.6
Aug 10-19.9N	75	.52	16.5	.10	19.3
Aug 20-29.9N	70	.85	9.7	.51	16.1
Jul-Aug-Sep:					
E-W	158	.82	12.4	.42	19.6
Rec.	158	.76	14.0	.42	19.6
10-19.9N	75	.62	15.2	.10	19.3
20-29.9N	70	.80	11.1	.51	16.1

c. September Data

Equation	Sample Size	Equation R.	Equation S.E.	Persistence R.	Persistence S.E.
Sep E-W	253	.56	19.4	.17	23.1
Sep Rec.	253	.58	19.0	.17	23.1
Sep 10-19.9N	140	.44	18.6	.19	20.3
Sep 20-29.9N	112	.68	17.7	.06	24.2
Jul-Aug-Sep:					
E-W	253	.66	17.7	.17	23.1
Rec.	253	.63	18.3	.17	23.1
10-19.9N	140	.51	17.8	.19	20.3
20-29.9N	112	.83	13.3	.06	24.2

was unknown whether a storm would be an east-west moving storm or a recurving storm, a 24-hour forecast was made using equations derived from each category of dependent data. Both July east-west and July recurving equations were used on July data. In addition, equations derived from the combined dependent sample months of July, August and September in both east-west and recurving categories were used for each monthly period. The future 24-hour change in intensity was obtained either from the appropriate equation in Appendix A, Table X or XI, or using persistence (past 24-hour change in intensity) and added to present intensity to give the 24-hour forecast intensity.

Parts a, b and c of Table VII are distributions of 24-hour forecasts of intensity using statistical regression equations. These are grouped by monthly periods from July through September. Part d. of Table VII, is the distribution of 24-hour forecasts using persistence. The forecasts made in Table VII, part d. were not subjectively modified in any manner, yet the average distribution by persistence corresponds very closely to the distribution of the forecasts by FWC/JTWC for 1970 and 1971 as shown previously. If samples are similar, this suggests the official forecasts in these years were nearly equivalent to persistence. In the following comparisons, forecast results better than a persistence forecast may then be considered better than official forecasts.

TABLE VII

Acceptability distribution of 24-hour intensity forecasts for independent data in percent of sample size.

a. July Data - Sample Size 174

Equation:	July East-West	July Recurving	Jul-Aug-Sep East-West	Jul-Aug-Sep Recurving
Accurate	44	42	49	47
Adequate	71	59	71	77
Useful	83	76	86	84
Inadequate	17	24	14	16

b. August Data - Sample Size 158

Equation:	August East-West	August Recurving	Jul-Aug-Sep East-West	Jul-Aug-Sep Recurving
Accurate	40	52	53	54
Adequate	79	82	82	83
Useful	87	89	91	91
Inadequate	13	11	9	9

c. September Data - Sample Size 253

Equation:	September East-West	September Recurving	Jul-Aug-Sep East-West	Jul-Aug-Sep Recurving
Accurate	44	38	43	42
Adequate	67	70	71	71
Useful	90	88	86	88
Inadequate	10	12	14	12

d. 24-Hour forecast using linear extrapolation (persistence)

Period:	July	August	September	Average
Accurate	25	38	30	31.1
Adequate	50	66	51	55.6
Useful	71	80	67	72.7
Inadequate	29	20	33	27.3

Each statistical regression equation gave much better performance than persistence. Persistence gave more useful information in August, and likewise the regression equations gave slightly more useful information in August. The following is an average of the distribution of forecasts for the three-month independent sample by equation category:

Equation:	Jul-Aug-Sep Recurving	Jul-Aug-Sep East-West	Indiv. Monthly E-W	Indiv. Monthly Rec.
Accurate	47.7	48.3	42.6	44.0
Adequate	77.0	74.7	72.3	70.3
Useful	87.7	87.7	86.7	84.3
Inadequate	12.3	12.3	13.3	15.7

In general, the regression equations derived from the combined three-month dependent sample gave better results than the equations derived from individual months, suggesting that equations derived from a larger sample are more accurate. In addition, the combined data equation is easier to apply. There was little difference in results whether using an equation derived from east-west or recurving data, indicating either equation could be applied with equal success. As a matter of convenience, the equation from combined monthly data should be used, thus eliminating the need to use a different equation for each month and for storms which extend into the next month.

b. Five-predictor equations derived from data within latitude bands

The data were next evaluated using the regression equations developed from storms in latitude bands.

TABLE VIII

Acceptability distribution of 24-hour intensity forecasts in percent of sample size for independent data in latitude band 10-19.9N.

a. July Data - Sample Size 69

Equation:	July 10-19.9N	Jul-Aug-Sep 10-19.9N	Persistence
Accurate	48	55	23
Adequate	81	83	51
Useful	93	93	85.5
Inadequate	7	7	14.5

b. August Data - Sample Size 75

Equation:	August 10-19.9N	Jul-Aug-Sep 10-19.9N	Persistence
Accurate	27	47	36
Adequate	58	76	56
Useful	75	87	81
Inadequate	25	13	19

c. September Data - Sample Size 140

Equation:	September 10-19.9N	Jul-Aug-Sep 10-19.9N	Persistence
Accurate	37	37	32
Adequate	65	69	54
Useful	84	86	72
Inadequate	16	14	28

d. Average for three-month period

Equation:	Individual Months	Jul-Aug-Sep 10-19.9N	Persistence
Accurate	37.3	46.2	30.3
Adequate	68	76.0	53.7
Useful	84	88.7	79.5
Inadequate	16	11.3	20.5

TABLE IX

Acceptability distribution of 24-hour intensity forecasts in percent of sample size for independent data in latitude band 20-29.9N.

a. July Data - Sample Size 92

Equation:	July 20-29.9N	Jul-Aug-Sep 20-29.9N	Persistence
Accurate	39	40	31.5
Adequate	70	70	55.5
Useful	85	85	68.5
Inadequate	15	15	31.5

b. August Data - Sample Size 70

Equation:	August 20-29.9N	Jul-Aug-Sep 20-29.9N	Persistence
Accurate	73	53	40
Adequate	90	87	74
Useful	97	94	78.5
Inadequate	3	6	21.5

c. September Data - Sample Size 112

Equation:	September 20-29.9N	Jul-Aug-Sep 20-29.9N	Persistence
Accurate	47	50	25
Adequate	74	78	46.5
Useful	87	93	61
Inadequate	13	7	39

d. Average for three month period

Equation:	Individual Months	Jul-Aug-Sep 20-29.9N	Persistence
Accurate	53	47.7	32.2
Adequate	78	78.3	58.7
Useful	89.7	90.7	69.3
Inadequate	10.3	9.3	30.7

Due to the lack of sufficient independent data in the bands 0-9.9N and 30-39.9N, the equations in these latitude bands were not evaluated. The approach used to evaluate each equation was to apply individual monthly equations and also combined July-August-September equations to monthly data in a given latitude band. Tables VIII and IX are acceptability distributions by months for 24-hour intensity forecasts in latitude bands using statistical regression equations from Tables XII and XIII, in Appendix A and also using persistence. Each equation performed better than persistence in 24-hour intensity forecasts except the equation derived from August data within 10-19.9N. Regression equations to forecast 24-hour intensity for July storms gave 93 percent useful information within 10-19.9N and 85 percent useful information within 20-29.9N (Table VIII). However, in August and September storms, regression equations gave more useful information within 20-29.9N than in the 10-19.9N band. Forecasts using regression equations gave more overall useful information within the 20-29.9N band, as seen by comparison of part (d) in Tables VIII and IX. Considering only persistence, more useful information was provided within the 10-19.9N band. Persistence forecasts yielded more useful information in July and August than in September, regardless of latitude.

Comparison of the distribution of useful information given in Tables VII, VIII and IX with the correlation coefficient (R) in Table VI provided some very

interesting results. The correlation coefficient was 0.74 for the Jul-Aug-Sep east-west and recurving equations in Table VI, part (a). Indeed the amount of useful information in Table VIII, part (a) was almost equal, being 86 and 84 percent respectively for the two equations. From Table VI, R for the July east-west equation was 0.73 and for the July recurving equation 0.53. As expected, the useful information decreased to 83 and 76 percent, respectively, for the two equations. This general trend was consistent throughout most of the comparisons. However, the actual magnitude of R when considering persistence compared to equations did not appear to be a good measure of usefulness. The correlation coefficient (R) of persistence for August data within 10-19.9N was 0.10 (from Table VI, part (b)), compared to R for the Jul-Aug-Sep 10-19.9N equation of 0.62. Considering the distribution of useful information in Table VIII, part (b), persistence yielded 81 percent and the equation yielded 87 percent. Although there was a marked difference in R, the amount of useful information was relatively close. The evaluation scheme examining R considers only absolute error and applies equal weight to an error regardless of the intensity of the storm, and focuses on normalized intensity changes, whereas the JTWC method focuses on actual intensity. This may account for the differences in the distribution of useful information in the FWC/JTWC method compared to the correlation coefficients.

Considering both latitude bands, 10-19.9N and 20-29.9N, the combined equation derived from July, August and September data produced equal or more useful information than equations derived from a single month. The following is a combined average of the distribution of the equations for the two latitude bands 10-19.9N and 20-29N:

Equation	Jul-Aug-Sep	Individual Monthly	Persistence
Accurate	46.9	45.2	31.2
Adequate	77.2	73.0	56.2
Useful	89.7	86.8	74.4
Inadequate	10.3	13.2	25.6

The overall averages indicated that two equations, namely Jul-Aug-Sep 10-19.9N and 20-29.9N, could be used for predicting future 24-hour change in intensity for any storm in the respective latitude band, regardless of the month of occurrence. These equations yield significantly better results than linear extrapolation and slightly better results than the individual monthly equations. The combined equations from Jul-Aug-Sep data in the latitude bands produced 89.7 percent useful information compared to 87.7 percent useful information from the combined data equations in east-west or recurving data. Thus only two five-parameter equations are required for forecasting 24-hour intensity of tropical cyclones in the months of July, August or September. One equation will apply to storms within 10-19.9N and the other for storms within 20-29.9N. Each equation gives significantly more useful data than

persistence, and thus can be expected to perform better than the present methods now being used by FWC/JTWC. As a storm moves out of these two latitude bands or occurs in other months, a variety of equations are available in Appendix A which will yield better results than simple extrapolation.

c. Ten-predictor equations

Equations using ten predictors were derived from the same data categories as the five-predictor equations. Each ten-predictor equation contained the five-parameters which made up the corresponding five-predictor equation as well as five additional parameters. Most of the five additional parameters were of statistical significance at the 5% level when considering the F-value upon entry. Although some ten-predictor equations contained predictors which were not significant at the 5% level, the overall F-value of each ten-predictor equation remained above the critical F-value for the 5% level.

Each ten-predictor equation provided more useful information than persistence when forecasting 24-hour intensity. However, considering the distribution of acceptable information from ten vice five-predictor equations, there was little difference. A comparison of the percent distribution of acceptable information from Jul-Aug-Sep combined data ten-predictor equations within 10-19.9N and 20-29.9N verses the corresponding five-predictor equation follows:

Independent Data	Ten-Predictor Equation Acc.	Ade.	Use.	Five-Predictor Equation Acc.	Ade.	Use.
Jul 10-19.9N	60	83	93	55	83	93
Aug 10-19.9N	46	72	88	47	76	87
Sep 10-19.9N	44	72	82	37	69	86
Jul 20-29.9N	43	73	87	40	70	85
Aug 20-29.9N	63	91	96	53	87	94
Sep 20-29.9N	44	73	94	50	78	93

As seen from the above, there was very little to be gained by using a ten-predictor equation vice a five-predictor equation, and certainly a shorter equation is much more desirable from an application point of view. Ten-predictor equations to predict actual 24-hour future intensity are presented in Appendix B with an evaluation of acceptable information in Table XVI.

IV. SUMMARY AND CONCLUSIONS

Statistical regression equations to predict future 24-hour change in intensity of tropical cyclones were derived from a history file of tropical cyclone data stratified by monthly periods into the following categories: (a) East-west moving storms, (b) Recurving storms, (c) All storms within latitude bands 0-9.9N, 10-19.9N, 20-29.9N and 30-39.9N. Storms were eliminated which (1) had an initial northeasterly heading which continued to move to the north-east, (2) had a genesis west of 125E, (3) had a first observation reporting a maximum intensity greater than 65 knots, (4) looped, i.e. formed a complete loop in the track. All data were considered over open ocean only. The dependent sample covered a ten-year period (1960-1969), and the independent test sample covered a five-year period (1955-1959).

Analysis of forecasts using the independent data sample indicated that the statistical regression equations could be used to determine future 24-hour changes in intensity of tropical cyclones with forecasts which are significantly more accurate than current methods based mainly on persistence.

Although typhoon intensity, size, and speed of movement varies with month (Liechty 1972), only two five-predictor equations were required to forecast 24-hour intensity

changes in the majority of July through September storms in the western North Pacific. The two equations predict intensity changes of tropical storms and typhoons occurring from July through September within a given latitude band. Since none of the past 24-hour predictors were selected for these equations, (Appendix A, Tables XII (g) and XIII (f)) only 12 hours of history are required before a forecast can be made. The five predictors are readily available to the forecaster, and within minutes, a forecast can be made using the equations. If tropical cyclones or typhoons occur outside the area or periods covered by these two equations, a variety of additional prediction equations from which the forecaster may choose are included in Appendix A.

The statistical regression equation to predict future 24-hour intensities of typhoons must be considered as only one additional tool to aid the forecaster. It must be remembered that the values of parameters required by these equations may contain errors, thus somewhat degrading the accuracy of the equations. The only real test will be with operational data rather than post-season smoothed, best track data. However, these equations, when combined with experience, synoptic data, subjective modifications, and climatological guides, should greatly improve the accuracy of present methods of typhoon intensity forecasting.

APPENDIX A

Statistical regression equations using five parameters to predict future 24-hour change in intensity in knots per 24 hours are presented. Tables X and XI are the monthly equations derived from east-west and recurving data respectively. Tables XII and XIII are the monthly equations derived from data within latitude bands 10-19.9N and 20-29.9N respectively. Table XIV presents the equations derived from data within 0-9.9N and 30-39.9N.

TABLE X

Regression equations derived from east-west data to predict future 24-hour change in intensity (kt/24hr).

(a) July

Predictor Z	Coefficient
CONSTANT	42.25240
1	-0.99618
10	-0.65633
50	-0.00996
52	-46.59335
54	0.85886

(b) August

Predictor Z	Coefficient
CONSTANT	-60.53868
2	0.86914
10	-0.68542
13	-1.12739
50	-0.00928
55	2.46833

(c) September

Predictor Z	Coefficient
CONSTANT	-88.32253
2	0.41633
11	0.58877
17	0.72737
39	1.69331
49	-0.00402

(d) October

Predictor Z	Coefficient
CONSTANT	-23.36911
13	2.06295
17	1.43920
42	0.81278
46	-1.10552
50	-0.02001

(e) November

Predictor Z	Coefficient
CONSTANT	1024.77002
1	-1.45327
14	-3.11491
17	1.14865
19	-10.17075
50	-0.00869

(f) December through June

Predictor Z	Coefficient
CONSTANT	7.25270
10	-1.15147
22	-3.81075
44	0.39751
46	-0.23558
49	-0.00099

(g) Jul-Aug-Sep

Predictor Z	Coefficient
CONSTANT	-22.35187
1	-0.87414
2	0.36726
10	-0.56878
17	0.48592
50	-0.00566

TABLE XI

Regression equations derived from recurving data to predict future 24-hour change in intensity (kt/24hr).

(a) July

Predictor Z	Coefficient
CONSTANT	-456.68408
10	-0.85937
15	-0.14767
39	1.11113
53	-0.66595
54	1.20949

(b) August

Predictor Z	Coefficient
CONSTANT	18.12944
1	-1.31838
10	-0.59213
11	0.61858
17	0.32553
49	-0.00481

(c) September

Predictor Z	Coefficient
CONSTANT	48.62646
1	-1.17217
10	-0.22306
17	0.40493
19	-4.64079
51	-188.81778

(d) October

Predictor Z	Coefficient
CONSTANT	48.51552
1	-1.26156
10	-0.68253
17	0.40350
49	-0.00197
52	-77.76389

(e) November

Predictor Z	Coefficient
CONSTANT	23.45758
1	-1.20643
5	0.03156
10	-0.85769
42	-1.59244
50	-0.00305

(f) December through June

Predictor Z	Coefficient
CONSTANT	-3.93260
1	-2.30894
10	-1.16680
11	0.39558
13	1.30513
49	-0.00369

(g) Jul-Aug-Sep

Predictor Z	Coefficient
CONSTANT	43.25537
1	-0.99846
10	-0.35953
11	-0.20295
17	0.43457
19	-3.10880

TABLE XII

Regression equations derived from data within 10-19.9N to predict future 24-hour change in intensity (kt/24hr).

(a) July

Predictor Z	Coefficient
CONSTANT	-381.99585
1	-0.83874
14	1.35827
18	0.38930
50	-0.01267
52	-64.10526

(b) August

Predictor Z	Coefficient
CONSTANT	-862.32739
10	-0.63809
14	2.52380
17	0.88987
49	-0.01949
51	2429.88159

(c) September

Predictor Z	Coefficient
CONSTANT	2.19348
10	-0.40875
44	-0.25284
46	0.86847
50	-0.00940
54	1.52462

(d) October

Predictor Z	Coefficient
CONSTANT	-0.28871
8	3.20133
10	-0.76968
11	0.42675
17	0.52139
49	-0.00426

(e) November

Predictor Z	Coefficient
CONSTANT	-31.20357
1	-2.32222
2	0.58671
10	-0.39322
42	0.29826
49	-0.00134

(f) December through June

Predictor Z	Coefficient
CONSTANT	37.49117
1	-2.25802
10	-1.10579
22	-1.63809
45	-0.15726
49	-0.00121

(g) Jul-Aug-Sep

Predictor Z	Coefficient
CONSTANT	-44.62602
2	0.38688
10	-0.48747
17	0.58992
46	0.63176
50	-0.00867

TABLE XIII

Regression equations derived from data within 20-29.9N to predict future 24-hour change in intensity (kt/24hr).

(a) July

Predictor Z	Coefficient
CONSTANT	372.08813
10	-0.76135
16	-1.16243
21	-4.78572
50	-0.00632
54	0.94574

(b) August

Predictor Z	Coefficient
CONSTANT	39.44713
1	-2.04376
2	0.24200
10	-0.59548
19	-7.04820
49	-0.00166

(c) September

Predictor Z	Coefficient
CONSTANT	16.51608
1	-0.63702
7	1.58331
10	-0.27586
51	-207.23415
55	5.46685

(d) October

Predictor Z	Coefficient
CONSTANT	47.95605
1	-5.54319
2	0.40305
3	0.03157
11	0.57115
49	-0.00417

(e) November through June

Predictor Z	Coefficient
CONSTANT	2.23611
5	0.03680
10	-0.20631
18	0.24642
42	-2.66799
50	-0.00538

(f) Jul-Aug-Sep

Predictor Z	Coefficient
CONSTANT	6.56849
10	-0.45188
19	-3.30801
49	-0.00063
40	-0.00373
55	4.98910

TABLE XIV

Regression equations derived from data within 0-9.9N and 30-39.9N to predict future 24-hour change in intensity (kt/24hr).

a. Jan through Dec within 0-9.9N

Predictor Z	Coefficient
CONSTANT	-2.86331
8	-3.37220
10	-1.45857
11	0.88116
46	-1.87045
49	-0.00389

b. Jan through Dec within 30-39.9N

Predictor Z	Coefficient
CONSTANT	-172.37785
15	-0.28473
16	0.67054
19	-2.12016
22	0.48649
50	-0.00462

APPENDIX B

Ten-predictor regression equations were derived to predict actual future 24-hour intensity of tropical cyclones using the data in Section II and the methods of Section III. Two equations were derived from combined July, August and September data within 10-19.9N and 20-29.9N, and are presented in Table XV. These ten-predictor equations were evaluated with the forecast verification scheme employed by FWC/JTWC, and the results are found in Table XVI. The distribution of useful information obtained from these equations which predicted actual future 24-hour intensity is very similar to the distribution obtained from forecasts using ten-predictor equations which predicted future 24-hour changes in intensity.

TABLE XV

Ten-predictor regression equations derived from combined July, August, and September data to predict actual future 24-hour intensity (in knots) of tropical cyclones within latitude bands.

(a) 10-19.9N

Predictor Z	Coefficient
CONSTANT	-73.9
2	0.56236
3	0.03201
10	-0.42194
11	1.50945
15	-0.18754
17	0.40647
19	1.92792
39	0.42303
49	-0.00303
50	-0.00391

(b) 20-29.9N

Predictor Z	Coefficient
CONSTANT	141.1
1	-1.25443
2	-0.25864
10	-0.47648
11	1.89980
16	-0.45965
17	-0.32026
19	-2.91058
50	-0.00449
51	-895.2
55	6.91715

TABLE XVI

Acceptability distribution of information in percent of sample size from 24-hour future intensity forecasts within latitude bands using ten-predictor equations.

(a) Jul-Aug-Sep 10-19.9N equation to predict actual intensity

Data within 10-19.9N	Jul (69)*	Aug (75)*	Sep (140)*
Accurate	61	46	46
Adequate	81	73	74
Useful	93	88	82
Inadequate	7	12	18

(b) Jul-Aug-Sep 10-19.9N equation to predict intensity change

Data within 10-19.9N	Jul (69)*	Aug (75)*	Sep (140)*
Accurate	60	46	44
Adequate	83	72	72
Useful	93	88	82
Inadequate	7	12	18

(c) Jul-Aug-Sep 20-29.9N equation to predict actual intensity

Data within 20-29.9N	Jul (92)*	Aug (70)*	Sep (112)*
Accurate	44	67	46
Adequate	68	90	73
Useful	82	97	92
Inadequate	18	3	8

(d) Jul-Aug-Sep 20-29.9N equation to predict intensity change

Data within 20-29.9N	Jul (92)*	Aug (70)*	Sep (112)*
Accurate	43	63	44
Adequate	73	91	73
Useful	87	96	94
Inadequate	13	4	6

*Denotes sample size

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Naval Postgraduate School Monterey, California 93940	Unclassified
	2b. GROUP

3. REPORT TITLE

Typhoon and Tropical Storm Intensity Forecasts using Statistical Regression Equations

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis, March 1973

5. AUTHOR(S) (First name, middle initial, last name)

Glenn G. Coltrane

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1973	59	10

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

Statistical regression equations were derived to predict future 24-hour changes in intensity of tropical storms and typhoons in the western North Pacific. The predictors were chosen from 55 parameters available at six-hourly observations of tropical storms and typhoons during the period 1960-1969. The dependent data were composited into six categories: east-west moving storms, recurving storms, and all storms within latitude bands 0-9.9N, 10-19.9N, 20-29.9N and 30-39.9N.

The forecast equations were evaluated on a five-year (1955-1959) sample of independent data and compared to the forecast verification scheme employed by Fleet Weather Center/Joint Typhoon Warning Center. Two five-predictor equations, which require only 12 hours of history, can predict intensity for the majority of storms within the period July-September, and give significantly better results than current intensity forecast methods.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Typhoon Intensity						
Tropical Cyclone Intensity						
Statistical Forecasts						

DD FORM 1 NOV 65 1473 (BACK)

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